# Introduction to Routing and Packet Forwarding

**Routing Protocols and Concepts – Chapter 1**

Cisco | Networking Academy®
Mind Wide Open™

# Objectives

- Identify a router as a computer with an OS and hardware designed for the routing process.

- Demonstrate the ability to configure devices and apply addresses.

- Describe the structure of a routing table.

- Describe how a router determines a path and switches packets.

# Router as a Computer

- Describe the basic purpose of a router
  - Computers that specialize in sending packets over the data network
  - They are responsible for interconnecting networks by selecting the best path for a packet to travel and forwarding packets to their destination

- Routers are the network center
  - Routers generally have 2 connections:
    - WAN connection (Connection to ISP)
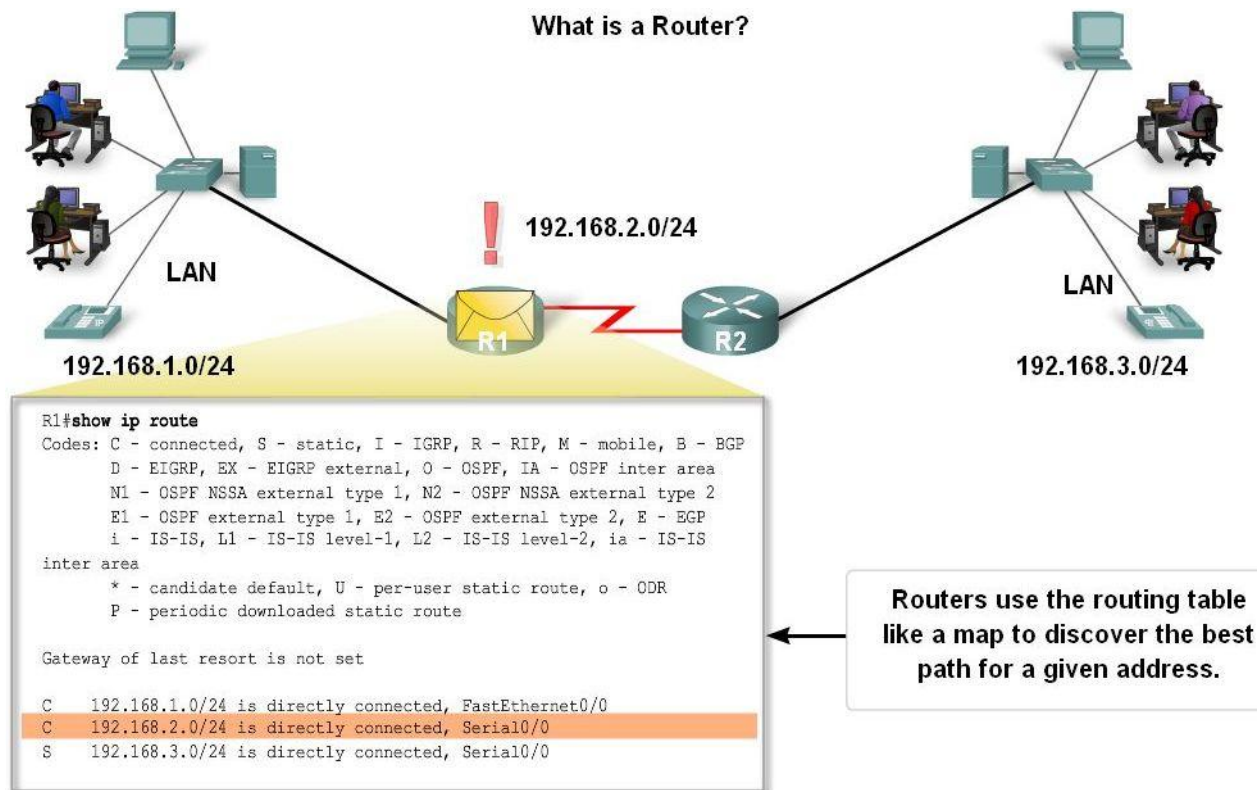    - LAN connection

# Router as a Computer

- Data is sent in form of packets between 2 end devices

- Routers are used to direct packet to its destination
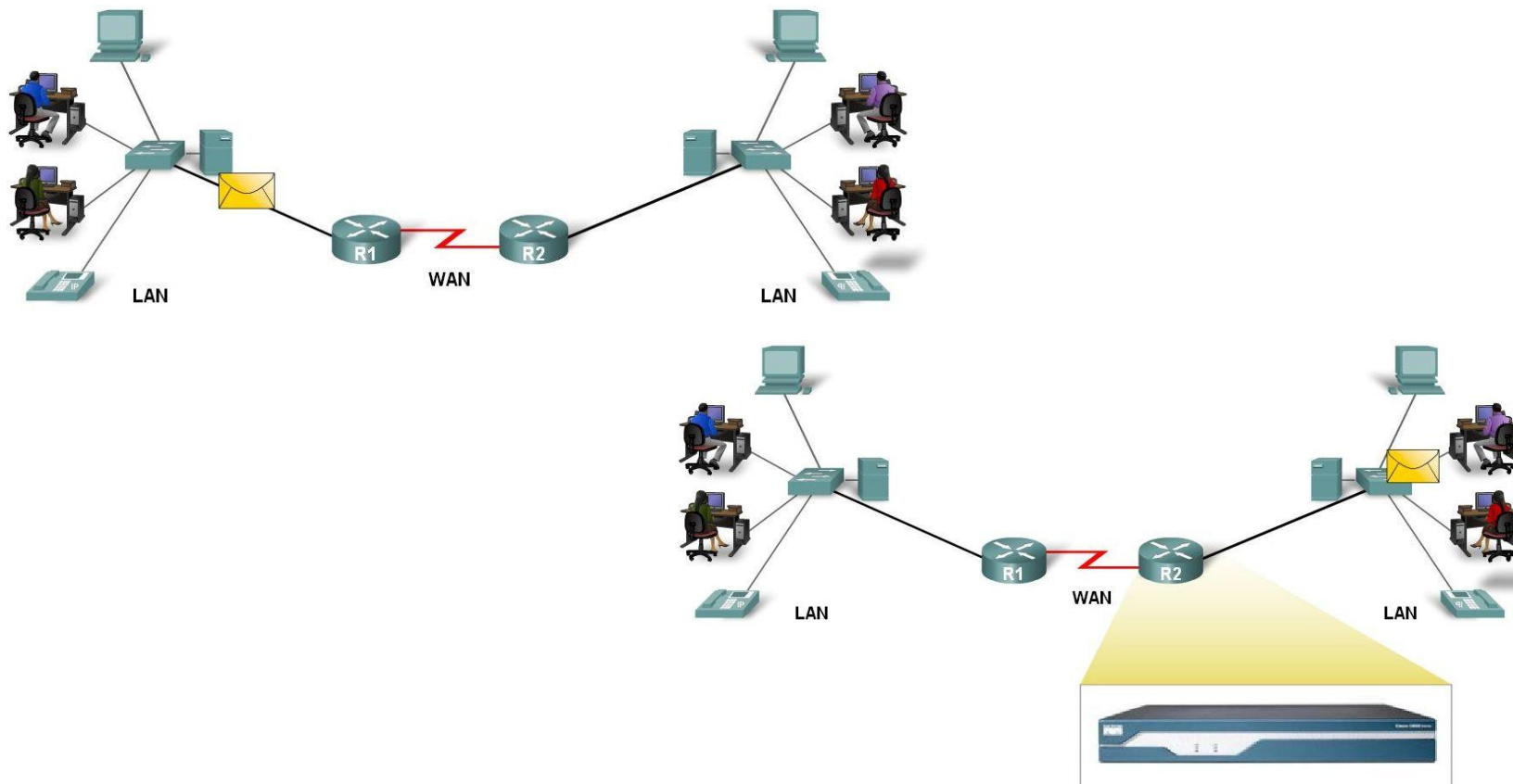


Routers direct packets to their proper destination. Routers connect different media.

# Router as a Computer

- Routers examine a packet's destination IP address and determine the best path by enlisting the aid of a routing table



**What is a Router?**

192.168.2.0/24

LAN

LAN

192.168.1.0/24

192.168.3.0/24

```
R1#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS
inter area
       * - candidate default, U - per-user static route, o - ODR
       P - periodic downloaded static route

Gateway of last resort is not set

C    192.168.1.0/24 is directly connected, FastEthernet0/0
C    192.168.2.0/24 is directly connected, Serial0/0
S    192.168.3.0/24 is directly connected, Serial0/0
```

Routers use the routing table like a map to discover the best path for a given address.
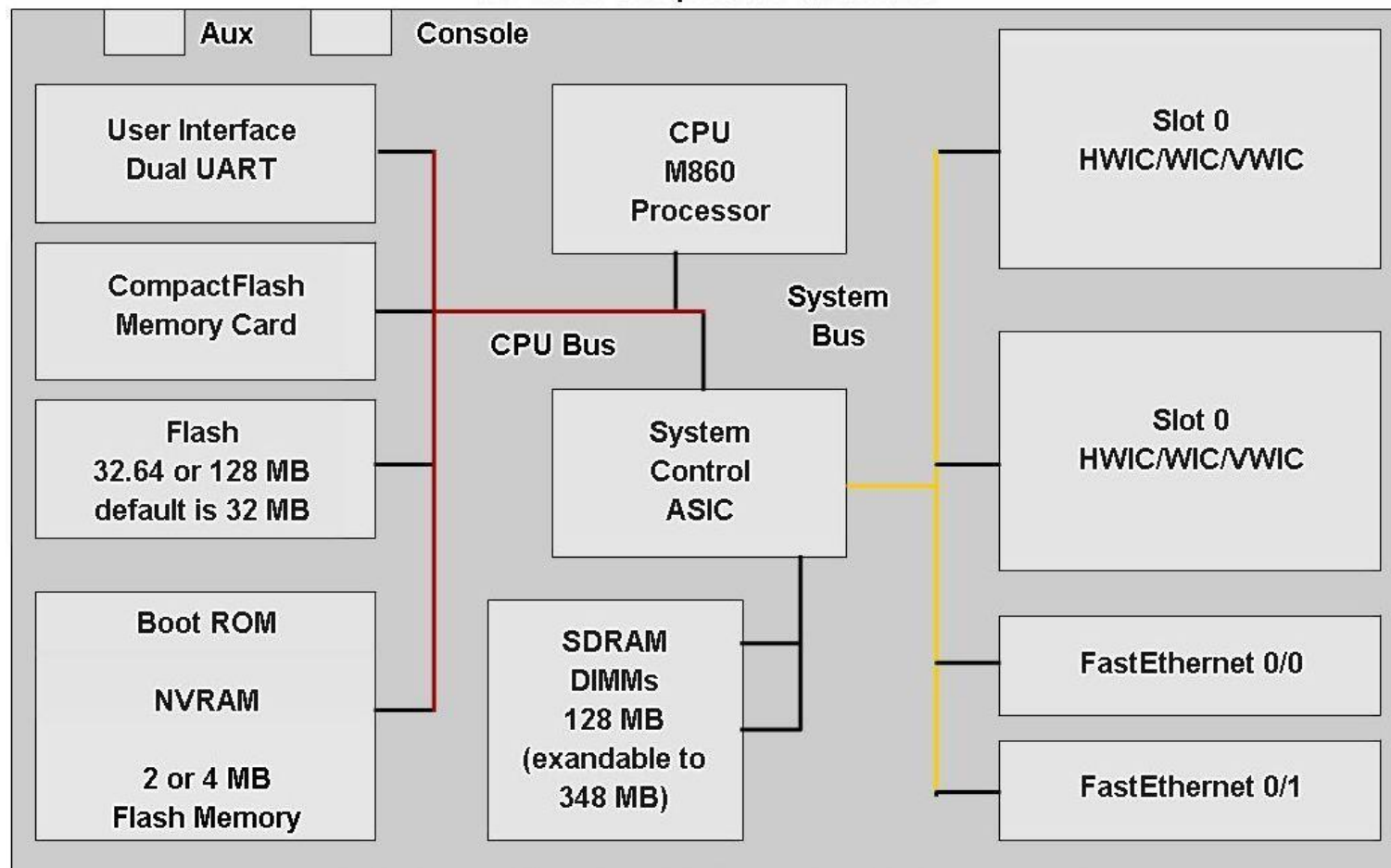
# Router as a Computer

- Router components and their functions:

    - CPU - Executes operating system instructions

    - Random access memory (RAM) - Contains the running copy of configuration file.  Stores routing table. RAM contents lost when power is off.

    - Read-only memory (ROM) - Holds diagnostic software used when router is powered up.  Stores the router's bootstrap program.

    - Non-volatile RAM (NVRAM) - Stores startup configuration. This may include IP addresses (Routing protocol, Hostname of router).

    - Flash memory - Contains the operating system (Cisco IOS).

    - Interfaces - There exist multiple physical interfaces that are used to connect network.  Examples of interface types:

        - Ethernet / fast Ethernet interfaces
        - Serial interfaces
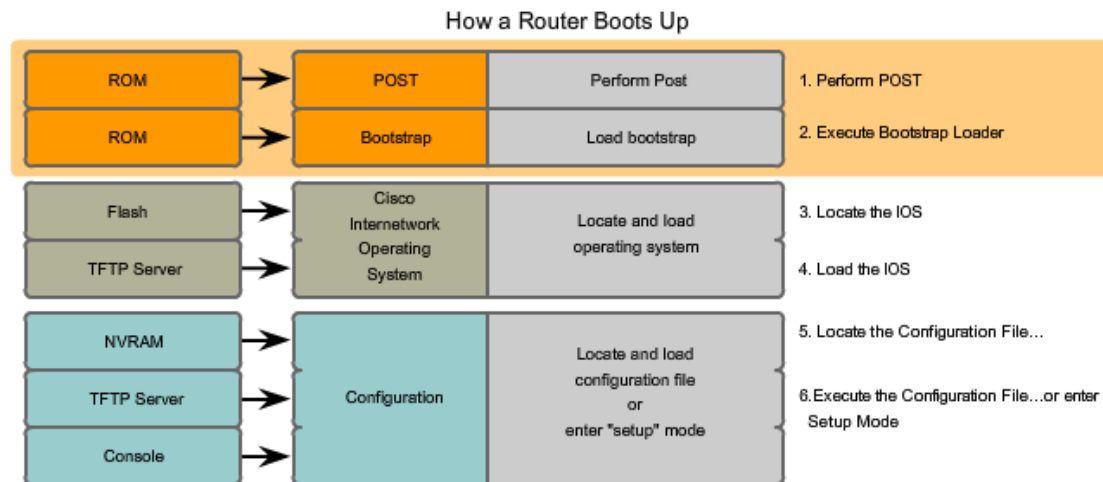        - Management interfaces

# Router as a Computer

- Router components

## Hardware components of a router



Aux

Console

| User Interface Dual UART | CPU M860 Processor | Slot 0 HWIC/WIC/VWIC |
| CompactFlash Memory Card | System Bus | |
| Flash 32.64 or 128 MB default is 32 MB | CPU Bus | Slot 0 HWIC/WIC/VWIC |
| | System Control ASIC | |
| Boot ROM NVRAM 2 or 4 MB Flash Memory | SDRAM DIMMs 128 MB (exandable to 348 MB) | FastEthernet 0/0 |
| | | FastEthernet 0/1 |

# Router as a Computer

- Major phases to the router boot-up process
  - Test router hardware
    - Power-On Self Test (POST)
    - Execute bootstrap loader
  - Locate & load Cisco IOS software
    - Locate IOS
    - Load IOS
  - Locate & load startup configuration file or enter setup mode
    - Bootstrap program looks for configuration file



How a Router Boots Up

| | | | |
|---|---|---|---|
| ROM | POST | Perform Post | 1. Perform POST |
| ROM | Bootstrap | Load bootstrap | 2. Execute Bootstrap Loader |
| Flash | Cisco Internetwork Operating System | Locate and load operating system | 3. Locate the IOS |
| TFTP Server | | | 4. Load the IOS |
| NVRAM | Configuration | Locate and load configuration file or enter "setup" mode | 5. Locate the Configuration File... |
| TFTP Server | | | 6. Execute the Configuration File...or enter Setup Mode |
| Console | | | |

# Router as a Computer

- Verify the router boot-up process:
  - The show version command is used to view information about the router during the bootup process. Information includes:
    - Platform model number
    - Image name & IOS version
    - Bootstrap version stored in ROM
    - Image file name & where it was loaded from
    - Number & type of interfaces
    - Amount of NVRAM
    - Amount of flash
    - Configuration register

# Router as a Computer

## How a Router Boots up

IOS version →
Bootstrap version →
Model and CPU →
Amount of RAM →
Number and type of interfaces →
Amount of NVRAM →
Amount of Flash →

```
Router#show version
Cisco Internetwork Operating System Software
IOS (tm) C2600 Software (C2600-I-M), Version 12.2(28), RELEASE SOFTWARE (fc5
Technical Support: http://www.cisco.com/techsupport
Copyright (c) 1986-2005 by cisco Systems, Inc.
Compiled Wed 27-Apr-04 19:01 by miwang
Image text-base: 0x8000808C, data-base: 0x80A1FECC

ROM: System Bootstrap, Version 12.1(3r)T2, RELEASE SOFTWARE (fc1)
Copyright (c) 2000 by cisco Systems, Inc.
ROM: C2600 Software (C2600-I-M), Version 12.2(28), RELEASE SOFTWARE (fc5)
System returned to ROM by reload
System image file is "flash:c2600-i-mz.122-28.bin"

cisco 2621 (MPC860) processor (revision 0x200) with 60416K/5120K bytes of memory.
Processor board ID JAD05190MTZ (4292891495)
M860 processor: part number 0, mask 49
Bridging software.
X.25 software, Version 3.0.0.

2 FastEthernet/IEEE 802.3 interface(s)
2 Low-speed serial(sync/async) network interface(s)
32K bytes of non-volatile configuration memory.
16384K bytes of processor board System flash (Read/Write)
Configuration register is 0x2102
Router#
```

# Router as a Computer

- Router Interface is a physical connector that enables a router to send or receive packets

- Each interface connects to a separate network

- Consist of socket or jack found on the outside of a router

- Types of router interfaces:
  - Ethernet
  - Fastethernet
  - Serial
  - DSL
  - ISDN
  - Cable

Each individual interface connects to a different network. Thus each interface has an IP address/mask from that network.
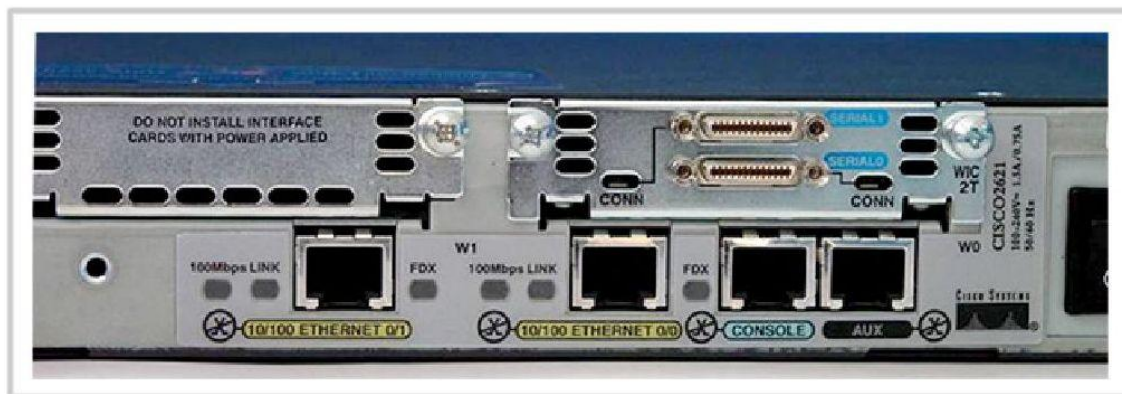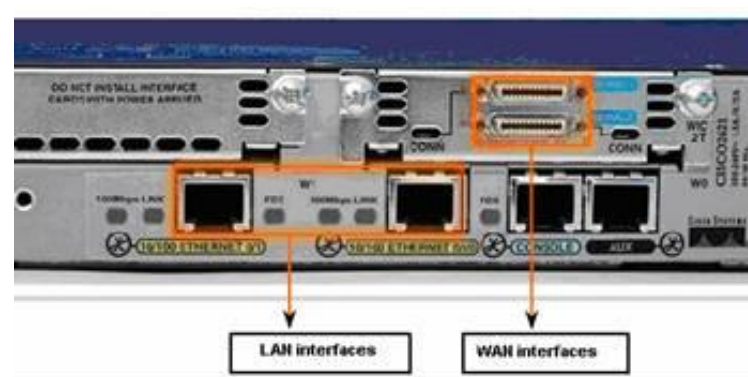
# Router as a Computer

- Two major groups of Router Interfaces
  - LAN Interfaces
    - Are used to connect router to LAN network
    - Has a layer 2 MAC address
    - Can be assigned a Layer 3 IP address
    - Usually consist of an RJ-45 jack
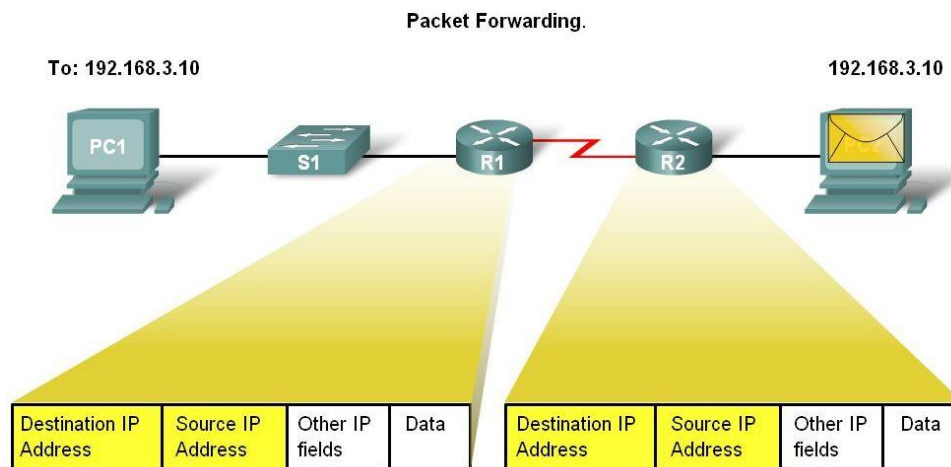  - WAN Interfaces
    - Are used to connect routers to external networks that interconnect LANs
    - Depending on the WAN technology, a layer 2 address may be used
    - Uses a layer 3 IP address



LAN interfaces    WAN interfaces

# Router as a Computer

- **Routers and the Network Layer**
  - Routers use destination IP address to forward packets
    - The path a packet takes is determined after a router consults information in the routing table
    - After router determines the best path
    - Packet is encapsulated into a frame
    - Frame is then placed on network medium in form of Bits

**Packet Forwarding.**

To: 192.168.3.10                                          192.168.3.10

PC1    S1    R1    R2

| Destination IP Address | Source IP Address | Other IP fields | Data | | Destination IP Address | Source IP Address | Other IP fields | Data |
|---|---|---|---|---|---|---|---|---|

**Each router examines the Destination IP address to correctly forward the packet.**
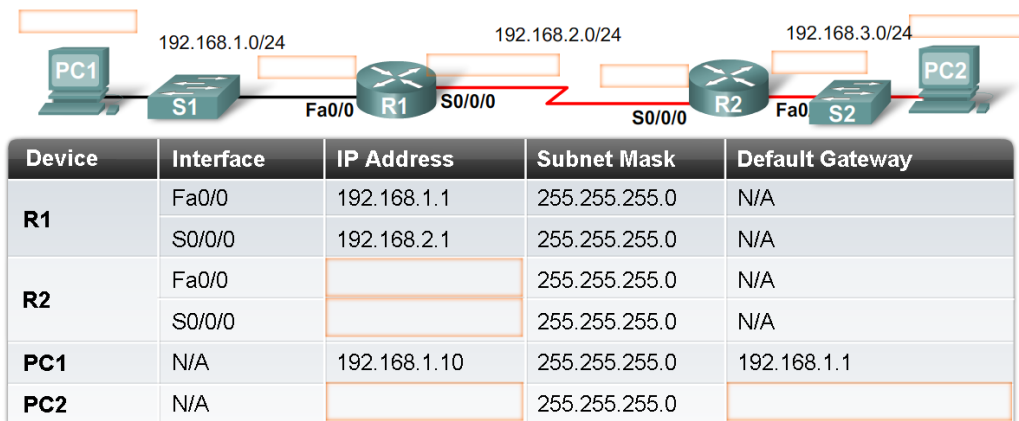
# Router as a Computer

- Routers Operate at Layers 1, 2 & 3
  - Router receives a stream of encoded bits
  - Bits are decoded and passed to layer 2
  - Router de-encapsulates the frame
  - Remaining packet passed up to layer 3
    - Routing decision made at this layer by examining destination IP address
  - Packet is then re-encapsulated & sent out outbound interface
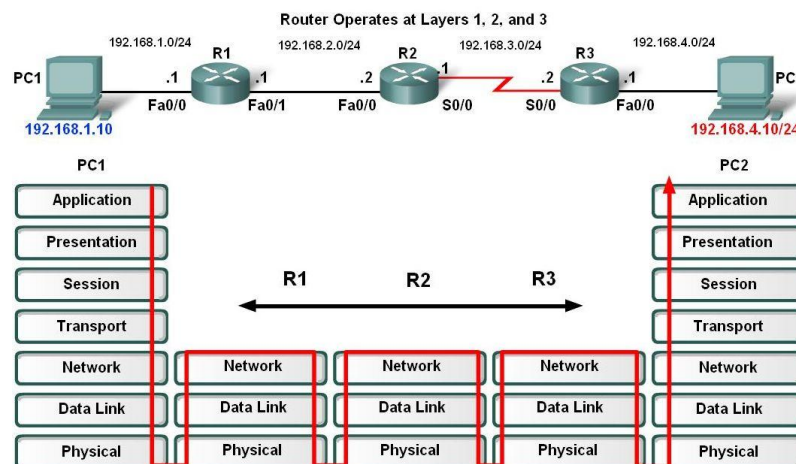
# Configure Devices and Apply Addresses

- Implementing Basic Addressing Schemes

- When designing a new network or mapping an existing network you must provide the following information in the form of a document:

  - Topology drawing that Illustrates physical connectivity

  - Address table that provides the following information:

    - Device name

    - Interfaces used

    - IP addresses

    - Default gateway

**Documenting an Addressing Scheme**



192.168.1.0/24    192.168.2.0/24    192.168.3.0/24

| Device | Interface | IP Address | Subnet Mask | Default Gateway |
|--------|-----------|------------|-------------|-----------------|
| R1 | Fa0/0 | 192.168.1.1 | 255.255.255.0 | N/A |
| | S0/0/0 | 192.168.2.1 | 255.255.255.0 | N/A |
| R2 | Fa0/0 | | 255.255.255.0 | N/A |
| | S0/0/0 | | 255.255.255.0 | N/A |
| PC1 | N/A | 192.168.1.10 | 255.255.255.0 | 192.168.1.1 |
| PC2 | N/A | | 255.255.255.0 | |

# Configure Devices and Apply Addresses

- Basic Router Configuration

  - A basic router configuration should contain the following:

    - Router name - Host name should be unique.

    - Banner - At a minimum, banner should warn against unauthorized use.

    - Passwords - Use strong passwords.

    - Interface configurations - Specify interface type, IP address and subnet mask.  Describe purpose of interface.  Issue no shutdown command.  If DCE serial interface issue clock rate command.

  - After entering in the basic configuration the following tasks should be completed:

    - Verify basic configuration and router operations.

    - Save the changes on a router.

# Configure Devices and Apply Addresses
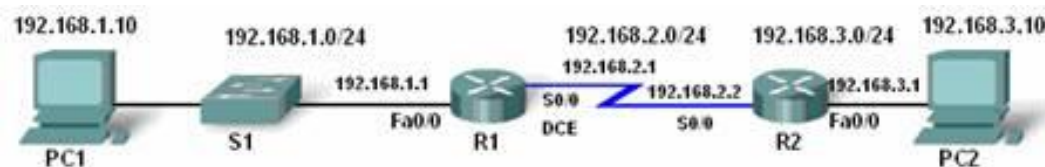


| Basic router configuration command syntax | |
|---|---|
| Naming the router | Router(config)# hostname name |
| Setting Passwords | Router(config)# enable secret password |
| | Router(config)# line console 0 |
| | Router(config-line)# password password |
| | Router(config-line)# login |
| | Router(config)# line vty 0 4 |
| | Router(config-line)# password password |
| | Router(config-line)# login |
| Configuring an interface | Router(config)# interface type number |
| | Router(config-if)# ip address address mask |
| | Router(config-if)# description description |
| | Router(config-if)# no shutdown |
| Configuring a message-of-the-day banner | Router(config)# banner motd # message # |
| Saving changes on a router | Router# copy running-config startup-config |
| Examining the output of show commands | Router# show running-config |
| | Router# show ip route |
| | Router# ip interface brief |
| | Router# interfaces |

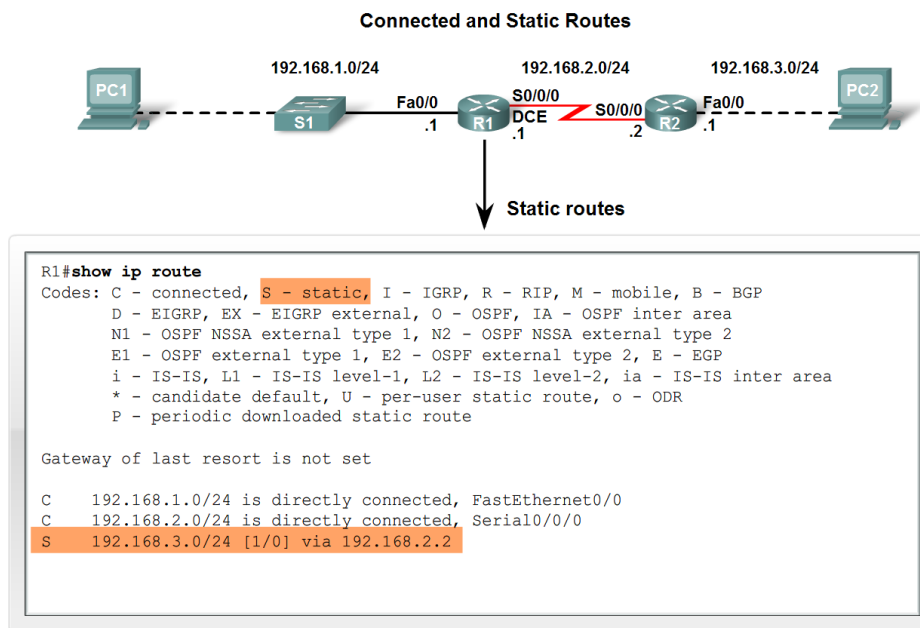# Configure Devices and Apply Addresses

- Verify Basic Router Configuration

  – Issue the *show running-config* command

  – Save the basic router configuration by issuing the *copy running-config startup-config* command

  – Additional commands that will enable you to further verify router configuration are:

    - Show running-config - Displays configuration currently in RAM

    - Show startup-config - Displays configuration file NVRAM

    - Show IP route - Displays routing table

    - Show interfaces - Displays all interface configurations

    - Show IP int brief - Displays abbreviated interface configuration information

# Routing Table Structure

- Routing Table is stored in ram and contains information about:

  - Directly connected networks - this occurs when a device is connected to another router interface

  - Remotely connected networks - this is a network that is not directly connected to a particular router

  - Detailed information about the networks include source of information, network address & subnet mask, and Ip address of next-hop router

- Show ip route command is used to view a routing table

# Routing Table Structure

- Adding a connected network to the routing table
  - Router interfaces
    - Each router interface is a member of a different network
    - Activated using the *no shutdown* command
    - In order for static and dynamic routes to exist in routing table you must have directly connected networks
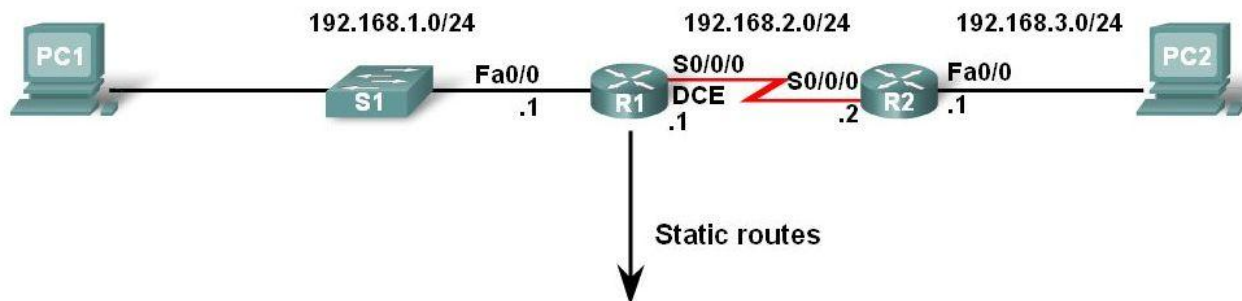
**Connected and Static Routes**



192.168.1.0/24          192.168.2.0/24          192.168.3.0/24

PC1                    Fa0/0   S0/0/0                  Fa0/0          PC2
          S1                 DCE    S0/0/0              .1
                    .1   R1   .1        .2   R2

**Static routes**

```
R1#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
       * - candidate default, U - per-user static route, o - ODR
       P - periodic downloaded static route

Gateway of last resort is not set

C    192.168.1.0/24 is directly connected, FastEthernet0/0
C    192.168.2.0/24 is directly connected, Serial0/0/0
S    192.168.3.0/24 [1/0] via 192.168.2.2
```
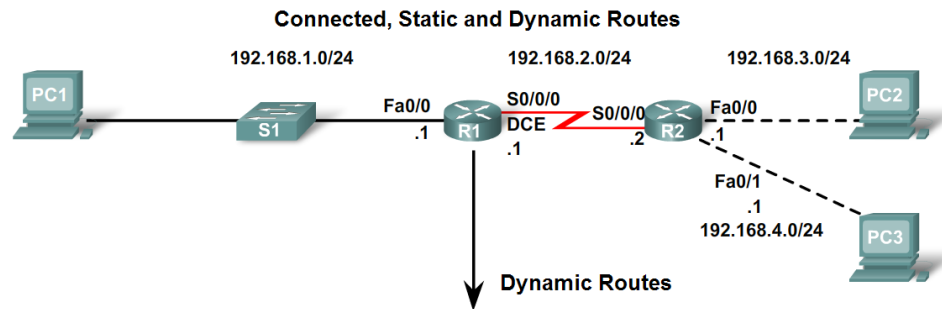
# Routing Table Structure

- Static routes in the routing table

  – Includes: network address and subnet mask and IP address of next hop router or exit interface

  – Denoted with the code **S** in the routing table

  – Routing tables must contain directly connected networks used to connect remote networks before static or dynamic routing can be used

- When to use static routes

  – When network only consists of a few routers

  – Network is connected to internet only through one ISP

  – Hub & spoke topology is used on a large network

# Routing Table Structure
- Connected and Static routes

**Connected and Static Routes**



```
R1#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
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S    192.168.3.0/24 [1/0] via 192.168.2.2
```

# Routing Table Structure

- Dynamic routing protocols

  - Used to add remote networks to a routing table

  - Are used to discover networks

  - Are used to update and maintain routing tables

- Automatic network discovery

  - Routers are able discover new networks by sharing routing table information

# Routing Table Structure

- Maintaining routing tables
  - Dynamic routing protocols are used to share routing information with other router & to maintain and up date their own routing table

- IP routing protocols - example of routing protocols include:
  - RIP
  - IGRP
  - EIGRP
  - OSPF

**Connected, Static and Dynamic Routes**



```
R1#show ip route
Codes:   C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
         D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
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         E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
         i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter
         area
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Gateway of last resort is not set
C    192.168.1.0/24 is directly connected, FastEthernet0/0
C    192.168.2.0/24 is directly connected, Serial0/0/0
S    192.168.3.0/24 [1/0] via 192.168.2.2
R    192.168.4.0/24 [120/1] via 192.168.2.2, 00:00:20, Serial0/0/0
```

# Routing Table Structure

- Routing Table Principles
  - 3 principles regarding routing tables:
    - Every router makes its decisions alone, based on the information it has in its routing table
    - Different routing table may contain different information
    - A routing table can tell how to get to a destination but not how to get back

**Routing Principle 3 in Action**

**R1 has a route to PC2's network.**

# Routing Table Structure

- Effects of the 3 Routing Table Principles
  - Packets are forwarded through the network from one router to another, on a hop by hop basis
  - Packets can take path "X" to a destination but return via path "Y" (Asymmetric routing)



Types of routing protocols

PC2

Which Path?

PC3

Send ping from PC1 to PC3

PC1
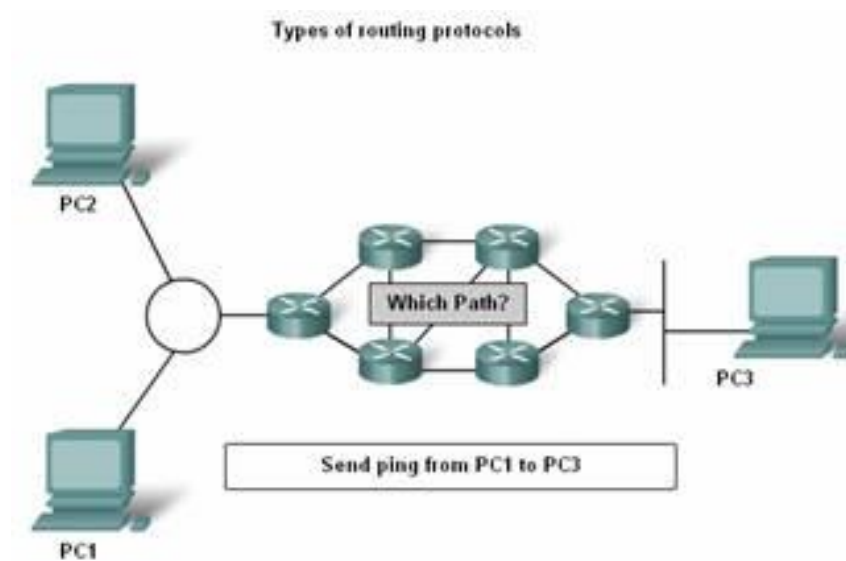
# Router Paths and Packet Switching

- Internet Protocol (IP) packet format contains fields that provide information about the packet and the sending and receiving hosts

- Fields that are importance for CCNA students:

  – Destination IP address

  – Source IP address

  – Version & TTL

  – IP header length

  – Precedence & type of service

  – Packet length

| Byte 1 | | Byte 2 | | Byte 3 | Byte 4 |
|---|---|---|---|---|---|
| | IHL | Service Type | | Packet Length | |
| Vers. | Identification | | Flag | Frag. Offset | |
| Time to Live | | Protocol | | Header Checksum | |
| | | Source Address | | | |
| | | Destination Address | | | |
| Options | | | | | Padding |

# Router Paths and Packet Switching

- **MAC Layer Frame Format**

- **MAC Frames are also divided into fields - they include:**
  - Preamble
  - Start of frame delimiter
  - Destination MAC address
  - Source MAC address
  - Type/length
  - Data and pad
  - Frame check sequence

**Ethernet Frame Fields**

**Ethernet**

**Field Length in Bytes**

| 8 | 6 | 6 | 2 | 46-1500 | 4 |
|---|---|---|---|---------|---|
| Preamble | Destination Address | Source Address | Type | Data | FCS |

**IEEE 802.3**

**Field Length in Bytes**

| 7 | 1 | 6 | 6 | 2 | 46-1500 | 4 |
|---|---|---|---|---|---------|---|
| Preamble | S O F | Destination Address | Source Address | Length | 802.2 Header and Data | FCS |

# Router Paths and Packet Switching

- A **Metric** is a numerical value used by routing protocols help determine the best path to a destination

    – The smaller the metric value the better the path

- 2 types of metrics used by routing protocols are:

    – Hop count - this is the number of routers a packet must travel through to get to its destination

    – Bandwidth - this is the "speed" of a link also known as the data capacity of a link

Hop Count vs Bandwidth as a Metric
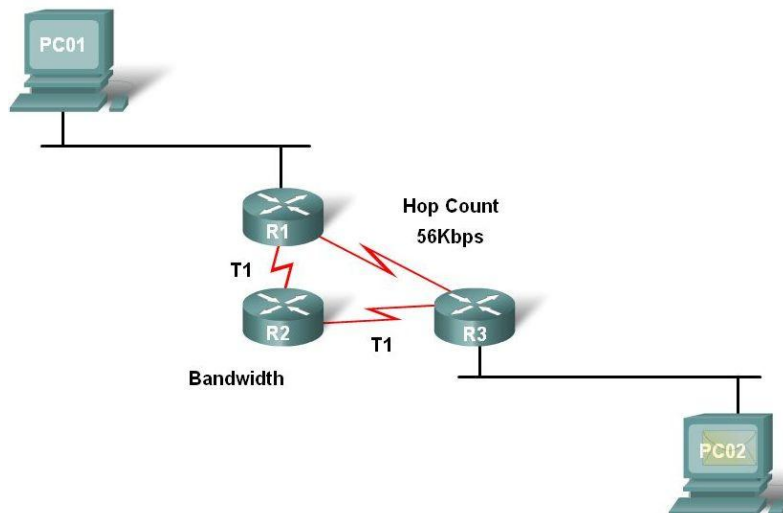
# Router Paths and Packet Switching

- **Equal cost metric** is a condition where a router has multiple paths to the same destination that all have the same metric

- To solve this dilemma, a router will use Equal Cost Load Balancing - this means the router sends packets over the multiple exit interfaces listed in the routing table.
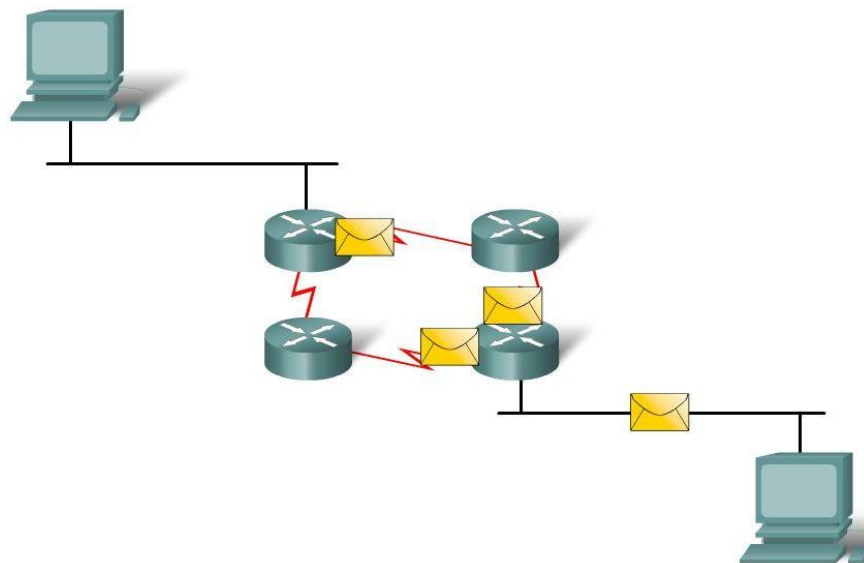
# Router Paths and Packet Switching

- **Path determination** is a process used by a router to pick the best path to a destination

- One of 3 path determinations results from searching for the best path

  - Directly connected network

  - Remote network

  - No route determined

**Finding the Best Path**

Which Path?
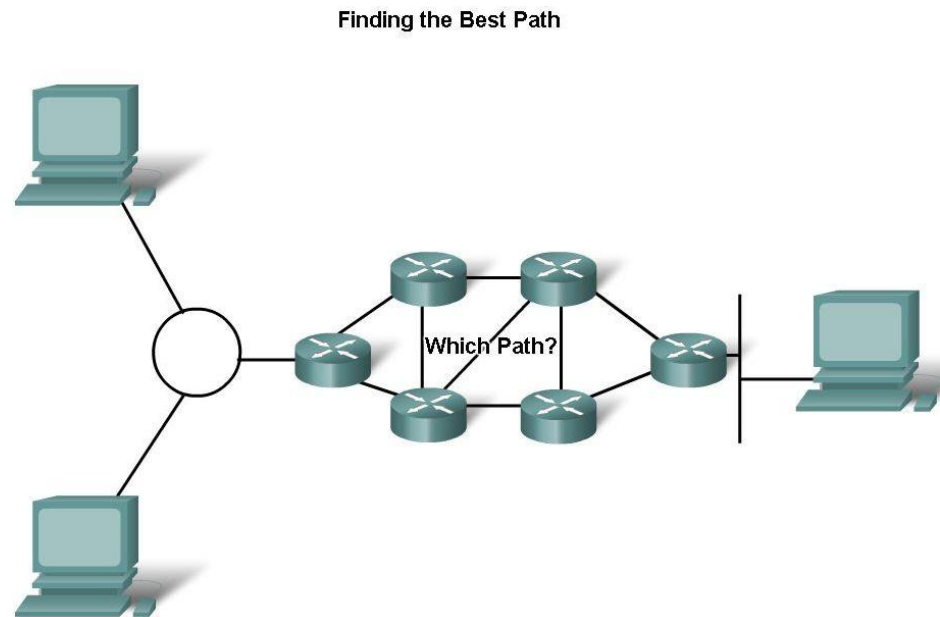
Routers determine the best path to the destination

# Router Paths and Packet Switching

- **Switching Function** of Router is the process used by a router to switch a packet from an incoming interface to an outgoing interface on the same router

  - A packet received by a router will do the following:

    - Strips off layer 2 headers

    - Examines destination IP address located in Layer 3 header to find best route to destination

    - Re-encapsulates layer 3 packet into layer 2 frame

    - Forwards frame out exit interface
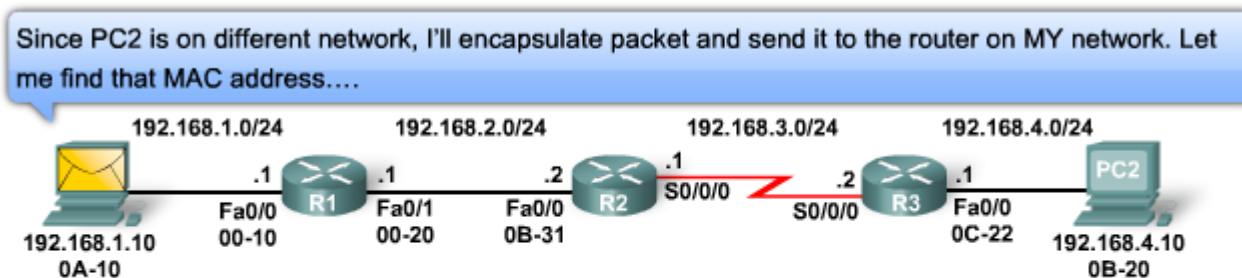
# Router Paths and Packet Switching

- As a packet travels from one networking device to another

  – The Source and Destination IP addresses **NEVER** change

  – The Source & Destination MAC addresses **CHANGE** as packet is forwarded from one router to the next

  – TTL field decrement by one until a value of zero is reached at which point router discards packet (prevents packets from endlessly traversing the network)
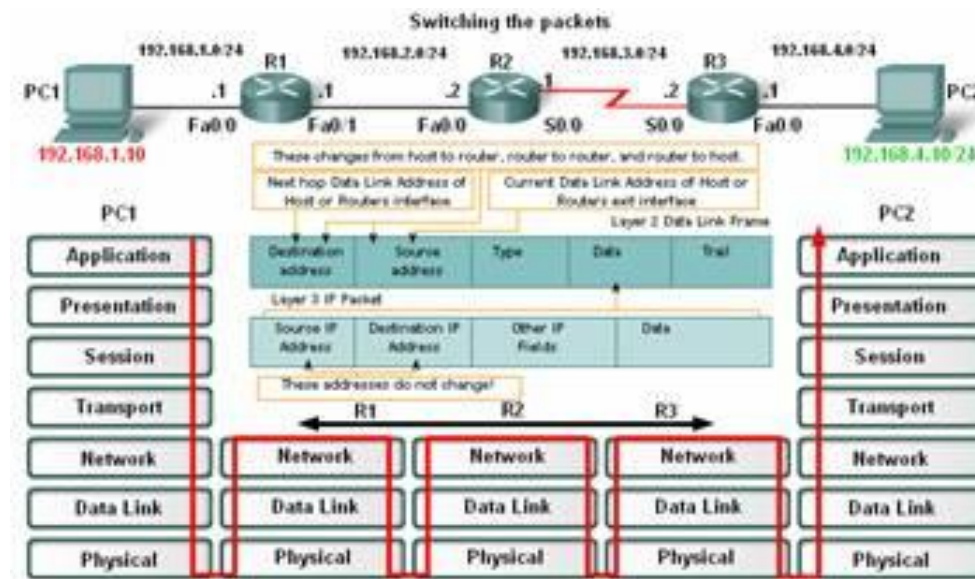
# Router Paths and Packet Switching

- Path determination and switching function details. PC1 wants to send something to PC 2.

  - **Step 1** - PC1 encapsulates packet into a frame - frame contains R1's destination MAC address



A day in the life of a packet: Step 1

# Router Paths and Packet Switching

- **Step 2** - R1 receives Ethernet frame
  - R1 sees that destination MAC address matches its own MAC
  - R1 then strips off Ethernet frame
  - R1 Examines destination IP
  - R1 consults routing table looking for destination IP
  - After finding destination IP in routing table, R1 now looks up next hop IP address
  - R1 re-encapsulates IP packet with a new Ethernet frame
  - R1 forwards Ethernet packet out Fa0/1 interface

# Router Paths and Packet Switching

A day in the life of a packet: Step 2



| 192.168.1.0/24 | 192.168.2.0/24 | 192.168.3.0/24 | 192.168.4.0/24 |
|---|---|---|---|

PC1
.1       R1      .1
Fa0/0           Fa0/1        Fa0/0        R2
00-10           00-20        0B-31
192.168.1.10
0A-10

.2     .1
S0/0/0

.2     R3     .1
S0/0/0        Fa0/0
               0C-22        PC2
                           192.168.4.10
                           0B-20

**Layer 2 Data Link Frame**      **Packet's Layer 3 data**
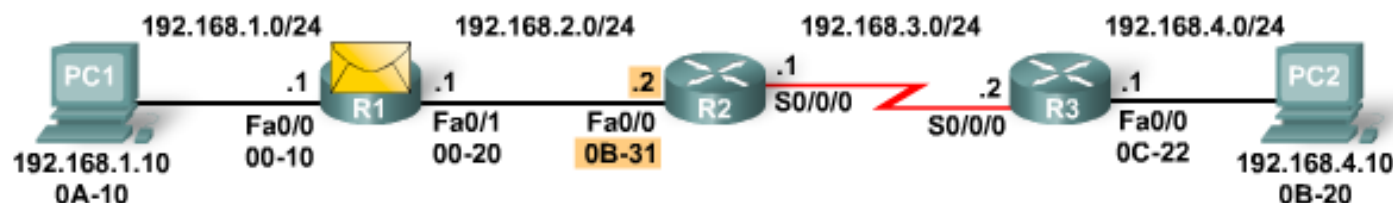
| Dest. MAC 0B-31 | | Type 800 | Dest. IP 192.168.4.10 | Source IP 192.168.1.10 | IP fields | Data | Trailer |
|---|---|---|---|---|---|---|---|
| | | | | | | | |

**R1's ARP Cache**

| IP Address | MAC Address |
|---|---|
| 192.168.2.2 | 0B-31 |

**R1's Routing Table**

| Network | Hops | Next-hop-IP | Exit Interface |
|---|---|---|---|
| 192.168.1.0/24 | 0 | Dir. Connect. | Fa0/0 |
| 192.168.2.0/24 | 0 | Dir. Connect. | Fa0/1 |
| 192.168.3.0/24 | 1 | 192.168.2.2 | Fa0/1 |
| 192.168.4.0/24 | 2 | 192.168.2.2 | Fa0/1 |

# Router Paths and Packet Switching

- **Step 3** - Packet arrives at R2
    - R2 receives Ethernet frame
    - R2 sees that destination MAC address matches its own MAC
    - R2 then strips off Ethernet frame
    - R2 Examines destination IP
    - R2 consults routing table looking for destination IP
    - After finding destination IP in routing table, R2 now looks up next hop IP address
    - R2 re-encapsulates IP packet with a new data link frame
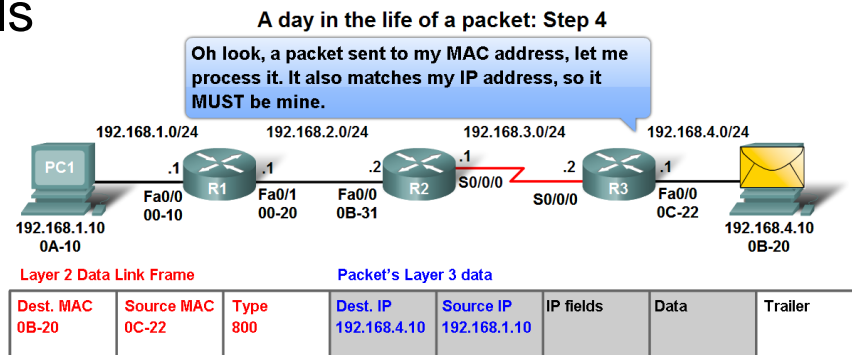    - R2 forwards Ethernet packet out S0/0 interface
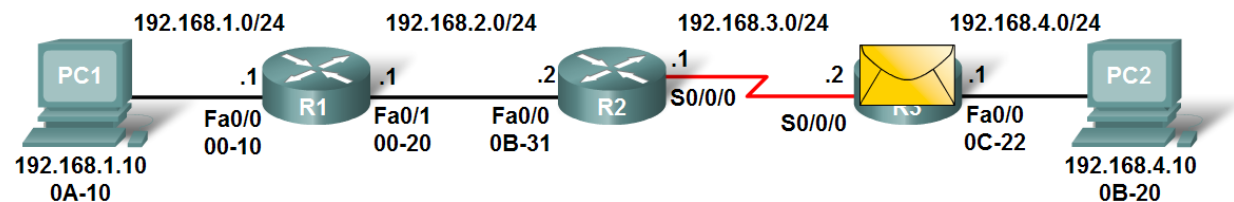


| | | Type 800 | Dest. IP 192.168.4.10 | Source IP 192.168.1.10 | IP fields | Data | Trailer |
|---|---|---|---|---|---|---|---|

Layer 2 Data Link Frame    Packet's Layer 3 data

# Router Paths and Packet Switching

- **Step 4** - Packet arrives at R3
  - R3 receives PPP frame
  - R3 then strips off PPP frame
  - R3 Examines destination IP
  - R3 consults routing table looking for destination IP
  - After finding destination IP in routing table, R3 is directly connected to destination via its fast Ethernet interface
  - R3 re-encapsulates IP packet with a new Ethernet frame
  - R3 forwards Ethernet packet out Fa0/0 interface
- **Step 5** - IP packet arrives at PC2 - frame is decapsulated and processed by upper layer protocols



A day in the life of a packet: Step 4

Oh look, a packet sent to my MAC address, let me process it. It also matches my IP address, so it MUST be mine.

Layer 2 Data Link Frame | Packet's Layer 3 data

| Dest. MAC | Source MAC | Type | Dest. IP | Source IP | IP fields | Data | Trailer |
|-----------|------------|------|----------|-----------|-----------|------|---------|
| 0B-20 | 0C-22 | 800 | 192.168.4.10 | 192.168.1.10 | | | |

# Summary

- Routers are computers that specialize in sending data over a network.
- Routers are composed of:
  - Hardware i.e. CPU, Memory, System bus, Interfaces
  - Software used to direct the routing process
    - IOS
    - Configuration file
- Routers need to be configured.  Basic configuration consists of:
  - Router name
  - Router banner
  - Password(s)
  - Interface configurations i.e. IP address and subnet mask
- Routing tables contain the following information:
  - Directly connected networks
  - Remotely connected networks
  - Network addresses and subnet masks
  - IP address of next hop address

# Summary

- Routers determine a packets path to its destination by the following:

  - Receiving an encapsulated frame & examining destination MAC address.

  - If the MAC address matches then Frame is de-encapsulated so that router can examine the destination IP address.

  - If destination IP address is in routing table or there is a static route then Router determines next hop IP address. Router will re-encapsulate packet with appropriate layer 2 frame and send it out to next destination.

  - Process continues until packet reaches destination.

  - Note - only the MAC addresses will change the source and destination IP addresses do not change.

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